INDUCTION HEATING OR MELTING POWER SUPPLY UTILIZING A TUNING CAPACITOR

Cross Reference To Related Applications

[0001] This application is a continuation-in-part of U.S. application serial no. 10/217,081, filed August 12, 2002, which claims priority to provisional patent application serial no. 60/312,159, filed August 14, 2001, the entirety of each of which are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates to an ac power supply for use in induction heating or melting applications wherein the induction power circuit is resonantly tuned.

Background of the Invention

[0003] **FIG. 1** illustrates a conventional power supply **110** that is used in induction heating or melting applications. The power supply consists of an ac-to-dc rectifier and filter section **112**, a dc-to-ac inverter section **120** and a tuning capacitor section **130**. For the power supply shown in **FIG. 1**, a three-phase diode bridge rectifier **114** converts three-phase (**A**, **B**, **C**) ac utility line power into dc power. Current limiting reactor $\mathbf{L_{108}}$ smoothes out the ripple in the output dc current of the rectifier, and capacitor $\mathbf{C_{108}}$ filters the ac component from the output dc voltage of the rectifier. The filtered dc output of the rectifier is inverted to ac by a full-bridge inverter consisting of solid state switches $\mathbf{S_{101}}$, $\mathbf{S_{102}}$, $\mathbf{S_{103}}$ and $\mathbf{S_{104}}$ and associated antiparallel diodes $\mathbf{D_{101}}$, $\mathbf{D_{102}}$, $\mathbf{D_{103}}$ and $\mathbf{D_{104}}$, respectively. Alternating turn-on/turn-off cycles of switch pairs $\mathbf{S_{101}/S_{103}}$ and $\mathbf{S_{102}/S_{104}}$ produce a synthesized ac inverter output at terminals **3** and **4**.

[0004] Induction load coil $\mathbf{L_{101}}$ represents the power coil used in the induction heating or melting application. For example, in an induction furnace, load coil $\mathbf{L_{101}}$, is wound around the exterior of a crucible in which metal charge has been placed. In an induction heating application, a metal workpiece, such as a strip or wire, may travel through a helical winding of load coil $\mathbf{L_{101}}$ or otherwise be brought near to the coil to inductively heat the workpiece. Current supplied by the power supply and flowing through load coil

L_{101} creates a magnetic field that either directly heats the metal charge or workpiece by magnetic induction, or heats the workpiece by heat conduction from a susceptor that is heated by magnetic induction. Load coil **L_{101}**, whether it be a single coil or an assembly of interconnected coil sections, has a very low operating power factor. Because of this, a tuning capacitor (or bank of capacitors), such as capacitor **C_{101}** must be provided in the load coil circuit to improve the overall power factor of the load coil circuit. These tuning capacitors are a significant cost and volume component of the power supply. Therefore, there exists the need for a power supply for inductive heating or melting applications that utilizes smaller and less costly tuning capacitors.

[0005] An objective of the present invention is to provide a power supply for inductive heating or melting applications that utilizes a capacitor connected between the output of the rectifier and the input of the inverter to form a resonantly tuned circuit with the induction load coil used in the application.

Brief Summary of the Invention

[0006] In one aspect, the present invention is apparatus for, and a method of, providing a power supply with rectifier and inverter sections for use with an induction load coil wherein a tuning capacitor is provided across the output of the rectifier and the input of the inverter to form a resonant circuit with the induction load coil. The induction load coil may comprise an active load coil connected to the output of the inverter, and a passive load coil connected in parallel with a capacitor to form a tank circuit. Other aspects of the invention are set forth in this specification and the appended claims.

Brief Description of the Drawings

[0007] For the purpose of illustrating the invention, there is shown in the drawings a form that is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

[0008] **FIG. 1** is a schematic diagram of a prior art power supply with a full-bridge inverter that is used in induction heating and melting applications.

[0009] **FIG. 2** is a schematic diagram of one example of the power supply of the present invention for use in induction heating or melting applications.

[0010] **FIG. 3** is a waveform diagram illustrating the inverter's output voltage and current for one example of the power supply of the present invention.

[0011] **FIG. 4** is a waveform diagram illustrating the voltage across a tuning capacitor and the current through a line filtering reactor used in one example of the power supply of the present invention.

[0012] **FIG. 5** is a waveform diagram illustrating the voltage across, and current through, a switching device used in the inverter in one example of the power supply of the present invention.

[0013] **FIG. 6** is a schematic diagram of another example of the power supply of the present invention for use in induction heating or melting applications.

[0014] **FIG. 7** is a vector diagram illustrating the advantages of an induction heating or melting system with the power supply of the present invention used with the load coil system illustrated in **FIG. 6**.

[0015] **FIG. 8** is a schematic diagram of another example of the power supply of the present invention for use in induction heating or melting applications.

[0016] **FIG. 9** is an isometric of one example of the physical arrangement of the inverter and tuning capacitor used in the power supply of the present invention.

[0017] **FIG. 10** is a top view of one example of the physical arrangement of the inverter used in the power supply of the present invention.

[0018] **FIG. 11(a)** is a cross sectional view of the physical arrangement of the inverter shown in **FIG. 10** along line **A-A**.

[0019] **FIG. 11(b)** is a cross sectional enlarged detail of the view in **FIG. 11(a)**.

[0020] **FIG. 12(a)** is an isometric of a typical film capacitor.

[0021] **FIG. 12(b)**is a cross section of the film capacitor shown in **FIG. 12(a)**.

[0022] **FIG. 13**(a) and **FIG. 13(b)** are one example of the physical arrangement of the tuning capacitor shown in FIG. 10.

[0023] **FIG. 14** is another example of the physical arrangement of the tuning capacitor shown in **FIG. 9**.

[0024] **FIG. 15** is another example of the physical arrangement of the tuning capacitor shown in **FIG. 9**.

[0025] **FIG. 16** is another example of the physical arrangement of the tuning capacitor shown in **FIG. 9**.

Detailed Description of the Invention

[0026] Referring to the drawings, wherein like numerals indicate like elements, there is shown in **FIG. 2** an illustration of one example of power supply **10** of the present invention for use in induction heating or melting applications. Ac-to-dc rectifier and filter section **12** includes an ac-to-dc rectifier. A multi-phase rectifier, in this non-limiting example of the invention, a three-phase diode bridge rectifier **14** is used to convert three-phase (**A**, **B**, **C**) ac utility line power into dc power. Optional current limiting reactor $\mathbf{L_8}$ smoothes out the ripple from the output dc current of the rectifier. Section **16** of the power supply diagrammatically illustrates coil tuning capacitor $\mathbf{C_1}$, which can be a single capacitor or a bank of interconnected capacitors that form a capacitive element.

[0027] In **FIG. 2**, the dc output of the rectifier is supplied to input terminals **1** and **2** of a full-bridge inverter in inverter section **20**. The inverter consists of solid state switches $\mathbf{S_1}$, $\mathbf{S_2}$, $\mathbf{S_3}$ and $\mathbf{S_4}$ and associated antiparallel diodes $\mathbf{D_1}$, $\mathbf{D_2}$, $\mathbf{D_3}$ and $\mathbf{D_4}$, respectively. Alternating turn-on/turn-off cycles of switch pairs $\mathbf{S_1/S_3}$ and $\mathbf{S_2/S_4}$ produce a synthesized ac inverter output at terminals **3** and **4**. A preferred, but not limiting, choice of component for the solid state switch is an isolated gate bipolar transistor (IGBT), which exhibits the desirable characteristics of power bipolar transistors and power MOS-FETs at high operating voltages and currents. In one example of the invention, the inverter employs a phase-shifting scheme (pulse width control) relative to the turn-on/turn-off cycles of the two switch pairs whereby variable overlapping on-times for the two switch pairs is used to vary the effective RMS output voltage of the inverter.

[0028] Induction load coil $\mathbf{L_9}$ represents the power coil used in the induction heating or melting apparatus. The capacitance of capacitor $\mathbf{C_1}$ is selected to form a resonant circuit with the impedance of load coil $\mathbf{L_9}$ at the operating frequency of the inverter, which is the switching rate of the switch pairs used in the inverter. Consequently, a tuning capacitor is not required at the output of the inverter. Selection of available circuit components may not allow operation exactly at resonance, but as close to resonance as is achievable with available components. The ac current flowing through induction load coil $\mathbf{L_9}$ from the output of the inverter magnetically couples with an electrically conductive material, which may be, for example, a conductive metal or a susceptor.

[0029] **FIG. 3** through **FIG. 5** illustrate the performance characteristics for power supply **10** of the present invention as shown in **FIG. 2** with input utility line power (**A**, **B**, **C**) of 480 volts line-to-line, 60 Hertz, and inverter **20** operating at an output frequency of 60 Hz. For this particular non-limiting example: $\mathbf{L_8}$ is selected as 5,000 μH (for an impedance of 3.77 ohms at the rectifier ripple output frequency of 120 Hz); $\mathbf{C_1}$ is selected as 5,000 μF (for an impedance of 0.27 ohms at the rectifier ripple output frequency of 120 Hz); and $\mathbf{L_9}$ is selected as 1,000 μH (for an impedance of 0.38 ohms at the inverter output frequency of 60 Hz). Not shown in **FIG. 2**, but used in this sample analysis is a resistance of 0.16 ohms for induction load coil $\mathbf{L_9}$. Operating the $\mathbf{C_1}/\mathbf{L_9}$ circuit at resonance for the output frequency of inverter **20** results in a substantially sinusoidal inverter output voltage, $\mathbf{V_{out}}$, and output current, $\mathbf{I_{out}}$ (at terminals **3** and **4**), as graphically illustrated in **FIG. 3**. **FIG. 4** graphically illustrates that the voltage across capacitor $\mathbf{C_1}$, namely $\mathbf{V_{C1}}$, is driven to its limiting lower value of zero volts as a result of capacitor $\mathbf{C_1}$ being in resonance with coil $\mathbf{L_9}$ at the ripple frequency of 120 Hz. $\mathbf{V_{C1}}$ is the applied voltage to the input of inverter **20** (at terminals **1** and **2**). **FIG. 4** also illustrates the ripple current, $\mathbf{I_{L8}}$, through reactor $\mathbf{L_8}$. The impedance of reactor $\mathbf{L_8}$ is generally selected to be much greater than the impedance of $\mathbf{C_1}$ to block feedback of harmonics from the inverter circuit to the rectifier's power source. **FIG. 5** graphically illustrates the voltage, $\mathbf{V_s}$, across one of the solid state switches in inverter **20**, and the current, $\mathbf{I_S}$, through one of the switches at maximum power output when there is zero overlap angle between $\mathbf{V_s}$ and $\mathbf{I_s}$. Switching device turn-off at zero volts for $\mathbf{V_s}$ when dc ripple has reached zero (e.g., at 240.0 milliseconds (ms) in **FIG. 4** and **FIG. 5**), will minimize switching loses. Additionally, since switching commutation occurs at zero voltage in this example, any spikes due to stray circuit

inductance will be significantly less than in a conventional inverter having low ac ripple current in the dc link voltage. This specific example is provided to illustrate the practice of the invention, which is not limited to the specific elements and values used in this example.

[0030] **FIG. 6** illustrates a second example of the present invention. In this example, the load coil consists of an active coil $\mathbf{L_1}$ and at least one passive coil $\mathbf{L_2}$. Coils $\mathbf{L_1}$ and $\mathbf{L_2}$ may be wound in one of various configurations, such as sequentially or overlapped, to accomplish mutual magnetic coupling of the coils as further described below. Coil $\mathbf{L_1}$ is connected to the output of inverter **20**. Coil $\mathbf{L_2}$ is connected in parallel with resonant tuning capacitor $\mathbf{C_2}$ to form a parallel tank resonant circuit. Coil $\mathbf{L_2}$ is not physically connected to coil $\mathbf{L_1}$. The parallel tank resonant circuit is energized by magnetically coupling coil $\mathbf{L_2}$ with the magnetic field generated in coil $\mathbf{L_1}$ when current supplied from the output of inverter **20** flows through coil $\mathbf{L_1}$.

[0031] The benefit of separate active and passive coils can be further appreciated by the vector diagram shown in **FIG. 7**. In the figure, with respect to the active coil circuit, vector **OV** represents current $\mathbf{I_1}$ in active coil $\mathbf{L_1}$ as illustrated **FIG. 6**. Vector **OA** represents the resistive component of the active coil's voltage, $\mathbf{I_1R_1}$ ($\mathbf{R_1}$ not shown in the figures). Vector **AB** represents the inductive component of the active coil's voltage, $\boldsymbol{\omega}\mathbf{L_1I_1}$ (where ω equals the product of 2π and f, the operating frequency of the power supply). Vector **BC** represents the voltage, $\boldsymbol{\omega}\mathbf{MI_2}$, induced by the passive coil $\mathbf{L_2}$ onto active coil $\mathbf{L_1}$. The half-wave ripple voltage $\mathbf{V_{C1}}$ across capacitor $\mathbf{C_1}$ and the switching function of the two switch pairs $\mathbf{S_1/S_3}$ and $\mathbf{S_2/S_4}$ produce the effect of a pseudo capacitor $\mathbf{C_1'}$ connected in series with $\mathbf{L_1}$ that would result in a sinusoidal voltage at terminals **5** and **6** in **FIG. 6**. Vector **CD** represents the voltage, $\mathbf{I_1/\boldsymbol{\omega} C_1'}$, that would appear across this pseudo series capacitor $\mathbf{C_1'}$. Vector **OD** represents the output voltage, $\mathbf{V_{inv}}$, of the inverter (terminals **3** and **4** in **FIG. 6**).

[0032] With respect to the passive coil circuit, vector **OW** represents current $\mathbf{I_2}$ in passive coil $\mathbf{L_2}$ that is induced by the magnetic field produced by current $\mathbf{I_1}$. Vector **OF** represents the resistive component of the passive coil's voltage, $\mathbf{I_2R_2}$ ($\mathbf{R_2}$ not shown in the figures). Vector **FE** represents the inductive component of the active coil's voltage, $\boldsymbol{\omega}\mathbf{L_2I_2}$. Vector **EG** represents the voltage, $\boldsymbol{\omega}\mathbf{MI_1}$, induced by the active coil $\mathbf{L_1}$ onto

passive coil L_2. Vector **GO** represents the voltage, $I_2/\omega C_2$, on capacitor C_2, which is connected across passive coil L_2.

[0033] The active coil circuit is driven by the voltage source, V_{inv}, which is the output of inverter **20**, while the passive coil loop is not connected to an active energy source. Since the active and passive coils are mutually coupled, vector **BC** is added to vector **OB**, V'_{LOAD}, which represents the voltage across an active induction load coil in the absence of a passive capacitive load coil circuit, to result in vector **OC**, V_{LOAD}, which is the voltage across an active load coil with a passive capacitive load coil circuit of the present invention. The resultant load voltage, V_{LOAD}, has a smaller lagging power factor angle, φ (counterclockwise angle between the x-axis and vector **OC**), than the conventional load coil as represented by vector **OB**. As illustrated in **FIG. 7**, there is a power factor angle improvement of $\Delta\varphi$.

[0034] In the present invention, the inductive impedance in the passive coil is substantially compensated for by the capacitive impedance (i.e., $\omega L_2 \approx 1/\omega C_2$). The uncompensated resistive component, R_2, in the passive coil circuit is reflected into the active coil circuit by the mutual inductance between the two circuits, and the effective active coil circuit's resistance is increased, thus improving the power factor angle, or efficiency of the coil system.

[0035] Further the power factor angle, Ψ, for the output of the inverter improves by $\Delta\Psi$ as illustrated by the angle between vector **OJ**, V'_{inv} (resultant vector of resistive component vector **OA** and capacitive component vector **AJ** in the absence of a passive load coil circuit) and vector **OD**, V_{inv} (resultant vector of resistive component vector **OH** and capacitive component vector **HD** with a passive load coil circuit of the present invention).

[0036] In other examples of the invention multiple active and/or passive coil circuits may be used to achieve a desired multiple coil arrangement for a particular application.

[0037] **FIG. 8** illustrates another example of the power supply of the present invention. In this example autotransformer **80** is connected to the ac output of the inverter. The autotransformer has a first output terminal and a plurality (at least two) of second output

terminals typically represented by autotransformer taps **100, 110** and **120** in **FIG. 8**. The first terminal of induction load coil $\mathbf{L_9}$ is connected to the autotransformer's first output terminal. The second terminal of the induction load coil is alternatively connected to one of the plurality of the autotransformer's second output terminals. The circuit impedance of the autotransformer changes with the connected tap, which changes the load circuit impedance so that the power supply in **FIG. 8** can selectively operate at approximate resonance at different output frequencies from the power supply. This is of advantage, for example, when an electrically conductive material is being inductively heated. As known in the art inductively heating at different frequencies will change the depth of induced heat penetration of the material. When different depths of heating are required the tap on the autotransformer can be changed to achieve this result with the power supply operating at approximate resonant frequency.

[0038] **FIG. 9** illustrates one example of the physical arrangement for coil tuning capacitor $\mathbf{C_1}$ and inverter elements, namely solid state switches $\mathbf{S_1}$, $\mathbf{S_2}$, $\mathbf{S_3}$ and $\mathbf{S_4}$ and associated antiparallel diodes $\mathbf{D_1}$, $\mathbf{D_2}$, $\mathbf{D_3}$ and $\mathbf{D_4}$, respectively, for the power supply of the present invention. This arrangement is particularly favorable for minimizing stray inductance associated with connections to the coil tuning capacitor and dc connections to the inverter elements. In this arrangement, coil tuning capacitor $\mathbf{C_1}$ is contained within enclosure **22** as further described below. In **FIG. 9** one or more physical terminals **24** represent electrical terminal **60** of capacitor $\mathbf{C_1}$ as shown in **FIG. 2**; similarly one or more physical terminals **26** (best seen in **FIG. 11(a)**) represent electrical terminal **62** of capacitor $\mathbf{C_1}$. Electrical insulators **25** may be provided for electrical isolation between the electrical conductors and enclosure **22**. Each solid state switch and its associated antiparallel diode may be physically provided as an integrally packaged switch/diode assembly **28a, 28b, 28c** and **28d** as shown in **FIG. 9** and **FIG. 2**. The four switch/diode assemblies are connected to form a full bridge inverter. First switch/diode assembly **28a** and second switch/diode assembly **28b** form a first pair of switch/diode assemblies that both have a first terminal connected to the positive connection of coil tuning capacitor $\mathbf{C_1}$; third switch/diode assembly **28c** and fourth switch/diode assembly **28d** form a second pair of switch/diode assemblies that both have a first terminal connected to the negative connection of coil tuning capacitor $\mathbf{C_1}$. The first terminals of the first and second pairs of switch/diode assemblies form the dc input to the inverter. The second terminals of the

first and fourth switch/diode assemblies are connected to a first ac output (AC1) of the inverter; the second terminals of the second and third switch/diode assemblies are connected to a second ac output (AC2) of the inverter. In **FIG. 9** physical electrical conductor **30**, represented by circuit terminal **1** in **FIG. 2**, connects positive capacitor physical terminals **24** (electrical terminal **60**) to the terminals of switch/diode assemblies **28a** and **28b** that correspond to electrical terminals **1** in **FIG. 2**. Similarly physical electrical conductor **34,** represented by circuit terminal **2** in **FIG. 2**, and connects negative capacitor physical terminals **26** (electrical terminal **62**) to the terminals of switch/diode assemblies **28c** and **28d** that correspond to electrical terminals **2** in **FIG. 2.** Physical electrical conductor **36** (via intermediate electrical conductors **36a** and **36b** joined together at electrically conductive connection **36c** as shown in **FIG. 11(a)** in this non-limiting example of the invention) is represented by circuit terminal **3** in **FIG. 2**, and connects terminals of switch/diode assemblies **28a** and **28d** (corresponding to first ac electrical terminal **3** in **FIG. 2**) to a first terminal of induction load coil $\mathbf{L_9}$ (not shown in **FIG. 10**). Similarly physical electrical conductor **38** (via intermediate electrical conductors **38a** and **38b** joined together at a suitable electrically conductive connection not shown in the figures, in this non-limiting example of the inverter) is represented by circuit terminal **4** in **FIG. 2**, and connects terminals of switch/diode assemblies **28b** and **28c** (corresponding to second ac electrical terminal **4** in **FIG. 2**) to a second terminal of induction load coil $\mathbf{L_9}$ (not shown in **FIG. 10**). It is one object of the present invention to keep the inductance in the physical connections between the tuning capacitor and dc input to the inverter as low as possible. Therefore, conductors **30** and **34** are preferably formed from a thin sheet material such as copper and sandwiched together with a thin layer of high dielectric strength material **33** (such as a MYLAR based dielectric) between them. Minimal thickness of the conductors and insulation keeps stray inductance to a minimum. It is also preferable to keep all dimensions of conductors **30** and **34** to the minimum required to make suitable connections.

[0039] Similarly it is desirable to maintain a low inductance circuit for the coil tuning capacitor $\mathbf{C_1}$. In one non-limiting arrangement of the invention, coil tuning capacitor $\mathbf{C_1}$ comprises one or more wound film capacitors **60** shown in a typical arrangement in **FIG. 12(a)** and in partial cross section in **FIG. 12(b)**. First capacitor conductor **61** is separated from adjacent second capacitor conductor **63** by dielectric layers **62** and **64**.

First capacitor conductor **61** extends to the top of the rolled capacitor, while second capacitor conductor **63** extends to the bottom of the rolled capacitor. A first electrical conductor in contact with the top of the rolled capacitor will form the first terminal of the capacitor and a second electrical conductor in contact with the bottom of the rolled capacitor will form the second electrical conductor.

[0040] In the arrangement shown in **FIG. 13(a)** and **FIG. 13(b)**, capacitors **60a** and **60b** are arranged on opposing sides of first and second capacitor connecting electrical conductors **66** and **68**, which are electrically separated by a dielectric **67**. As with the conductors between the terminals of the coil tuning capacitor and the dc input to the inverter, in order to kept the inductance low, conductors **66** and **68** are preferably formed from a thin sheet material such as copper and sandwiched together with a thin layer of high dielectric strength material **67** (such as a MYLAR based dielectric) between them.

[0041] Capacitors **60a** have their second (bottom) capacitor conductors **63** electrically in contact with first connecting electrical conductor **66**. Capacitors **60b** have their first (top) capacitor conductors **61** in contact with second connecting electrical conductor **68**. Capacitors **60a** have their first (top) capacitor conductors **61** electrically in contact with second connecting electrical conductor **68** by electrical conductor **70a**, and capacitors **60b** have their second (bottom) capacitor conductors **63** electrically in contact with first connecting electrical conductor **66** by electrical conductor **70b**. Electrical conductors **70a** and **70b** may be in the form of a copper rod passing through the center (spool) of each capacitor with an extending electrical conducting element at each end so that the first end of the copper rod makes contact with a capacitor's conductor that is not in contact with either connecting electrical conductor **66** or **68**, and the second end makes contact with either connecting electrical conductor **66** or **68**. Electrical insulation **67** is provided around electrical conductors **70a** and **70b** so that they do not make electrical contact with a connecting electrical conductor that would short out a capacitor. The extending electrical conducting element may be in the form of a copper plate **70c**. Connecting electrical conductors **66** and **68** extend out of enclosure **22** to form first and second capacitor terminals **24** and **26**.

[0042] In the alternative arrangement shown in **FIG. 14**, capacitors **60c** have their second (bottom) capacitor conductors **63** electrically connected to first connecting electrical

conductor **66**. The first (top) capacitor conductor **61** of each capacitor **60c** is electrically connected to second connecting electrical conductor **68** via electrical conductors **70a** with suitable extending electrical conducting elements **70c**.

[0043] In the alternative arrangement shown in **FIG. 15**, first connecting electrical conductor **66** may be press fitted around one or more capacitors **60d**. In this arrangement first (top) capacitor conductor **61** makes electrically contact with connecting electrical conductor **66** and second (bottom) capacitor conductor **63** makes electrical contact with connecting electrical conductor **68**.

[0044] In the alternative arrangement shown in **FIG. 16**, first and second connecting electrical conductors **66** and **68** may be press fitted around one or more capacitors **60e**. In this arrangement first (top) capacitor conductor **61** makes electrically contact with connecting electrical conductor **66** and second (bottom) capacitor conductor **63** makes electrical contact with connecting electrical conductor **68**.

[0045] In all alternative arrangements of capacitors, conductors **66** and **68** are preferably formed from a thin sheet material such as copper and sandwiched together with a thin layer of high dielectric strength material **67** between them.

[0046] The examples of the invention include reference to specific electrical components. One skilled in the art may practice the invention by substituting components that are not necessarily of the same type but will create the desired conditions or accomplish the desired results of the invention. For example, single components may be substituted for multiple components or vice versa. Further one skilled in the art may practice the invention by rearranging components to create the desired conditions or accomplish the desired results of the invention. While the examples illustrate operation of the invention in full-bridge voltage-fed power supplies, the invention is applicable to other power supply topologies with appropriate modifications as understood by one who is skilled in the art.

[0047] The foregoing examples do not limit the scope of the disclosed invention. The scope of the disclosed invention is further set forth in the appended claims.